School of Science & Technology

BEng/MEng (Hons) Aerospace Engineering
BEng/MEng (Hons) Civil and Infrastructure Engineering
BEng/MEng (Hons) Engineering System,
BEng/MEng (Hons) Mechanical and Design Engineering

EG1007: Introduction to Programming
Group Coursework

Introduction

This is a group coursework that is to be submitted in Moodle by 23:59 15th December, 2023. You need to work with your group members to complete the tasks specified in the following sections. The details of the groupings can be found in a separate document in Moodle.

You are required to submit Python scripts that respond to the brief below. The scripts shall be ready to run and contain sufficient comments explaining different parts, the use of built-in and user-defined functions, and the numerical schemes used to complete the tasks. Good examples of comments can be found in the code repository in Moodle. You shall not submit any additional documents, reports or plots. The numerical results and plots shall be displayed after running the submitted scripts.

You are encouraged to review the Python codes in the repository when writing your own scripts. However, you shall not directly use those codes for this coursework. Any potential case of plagiarism will be investigated based on the comments that you need to include in the script to describe them using your own words, the coding structures and declarations of variables. If plagiarism is found it will be considered as serious academic misconduct and you will be invited to defend the originality of your work in an interview.

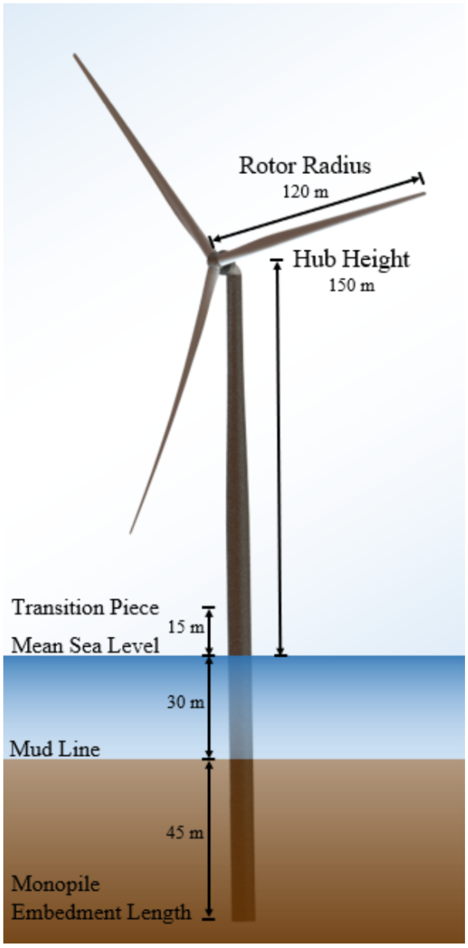

Figure 1: sketch of wind turbine system (www.nrel.gov)

Tasks

You are asked to analyse various problems associated with an offshore wind turbine system as sketched in Figure. 1. This includes the statistics on the power production, analysis of the environmental conditions and environmental load on the wind turbine. You need to use NumPy and matplotlib to complete the tasks.

1) Data analysis on power production (25 marks)

The file 'windturbinepower.txt' contains the time history of the power generated by the wind turbine. There are two columns of data in the file. The first column is the time *t* in seconds and the second is the power *P* in watts. Complete the following tasks

i) Use NumPy to read the data and analyse the maximum power, mean power and the standard deviation.

ii) Use matplotlib to plot a curve shows the variation in power with time.

iii) Estimate the rate of change of power with time (i.e. dP/dt) at different time instants using appropriate finite difference schemes with a consistent order of $O(dt^2)$.

2) Interpolating lift coefficients (25 marks)

The file 'liftcoeff.txt' contains the lift coefficient C_l of the turbine blade subjected to different attack angles, θ, which are the angles between the wind velocity and the blade. The first column of the data in the file is the attack angles in degrees and the second column is the lift coefficient. For a specific lift coefficient, the corresponding force can be found by $\frac{1}{2}\rho V^2 A$ where ρ is the density of the fluid (i.e. air in this task), V is the relative velocity between the wind and the rotating blade, A is the projection area of the blade perpendicular to the wind direction.

i) Using NumPy to load the data from the file, sort the data using the attack angle in ascending order (i.e. the first pair of data has the lowest attack angle)

ii) Using Newton's Divided Difference Interpolation find the lift coefficient of the blade when the attack angle is 11 degrees using a linear polynomial. You need to select the two best data points and fit a linear polynomial using $C_l(\theta) = b_0 + b_1(\theta - \theta_0)$, where b_0 and b_1 are the coefficients to be determined and θ_0 is the attack angle of one of the data points chosen.

iii) To improve the accuracy, a third order polynomial $C_l(\theta) = a_0 + a_1\theta + a_2\theta^2 + a_3\theta^3$ where a_0, a_1, a_2 and a_3 are the coefficients to be determined, will be used to find a second approximation of the lift coefficient at $\theta = 11$ degrees. Select the 4 best sets of data to determine the coefficients a_0, a_1, a_2 and a_3 and approximate the lift coefficient at $\theta = 11$ degree.

iv) Use $\frac{|f_n - f_a|}{f_a} \times 100\%$ and the approximate lift coefficient obtained in iii) to evaluate the relative error of the prediction in ii) , where f_n and f_a are the estimated and reference values, respectively.

Note: when choosing the appropriate data sets for the interpolation, you need to write the Python code to automatically select the best data sets using the difference between the attack angle of interest and the attack angles for which you have data. You are also expected to produce a figure comparing the data in the file, the linear interpolation function in ii) and the third-order polynomial in iii).

3) Integration to evaluate the wind load (25 marks)

The wind turbine blade, tower and monopile foundation are subjected to the action of the environmental factors, e.g. the wind, wave and current. In this task, you are asked to evaluate the wind drag acting on the wind turbine tower, i.e. the section of the pile from the mean water surface to the hub. It is assumed that (1) the effect of the blade can be ignored; and (2) the diameter of the circular cross-section *D* of the tower is uniform, i.e. 10 m. Under such conditions, the wind load can be calculated using

$$F_D = \frac{1}{2} C_d \rho D \int_0^h V^2 dz$$

in which $C_d = 0.6$ is the drag coefficient, D = 10 m, $\rho = 1.29$kg/m3 is the air density, h is the height of the hub, i.e. 150 m in this problem, and *V* is the velocity of the wind. Based on the weather condition, the wind is assumed to be steady and its profile, i.e. the wind speed at different location z, is

$$V(z) = V(H)(z/H)^{0.12}$$

in which H = 10 m, which is the reference altitude at which a forecast wind speed V(H) has been provided. In this problem, V(10) is 12.5 m/s.

i) Define the function V(z) in Python

ii) Divide the tower into 6 divisions, i.e. 7 points from z = 0 (mean water surface) to z = 150 m (hub), and generate the wind speed at these points using V(z). Visualise the data using matplotlib.

iii) Using the repeated trapezium rule and the repeated Simpson's rule, evaluate the wind drag by integrating $\frac{1}{2} C_d \rho D \int_0^h V^2 dz$.

iv) In order to secure a satisfactory result, you will need to carry out a series of integrations using the repeated Simpsons Rule with the number of divisions increasing each time the integration is repeated, e.g.12, 24, 48…. You can do this using a while loop. The loop will be terminated when the difference between results from two consecutive integrations with different divisions is sufficiently small.

4) Differentiation and structural vibration (25 marks)

In practice, the blade and the tower may vibrate, due to environmental loading. One day, the structural monitoring sensor recorded a time history of the oscillating velocity of the hub. After analysis, the following equation was derived to describe the horizontal velocity of the hub.

$$V_h(t) = 0.4\sin(2\pi t)\exp(-0.618t)$$

i) Write a Python code to predict the horizontal displacement of the hub at t = 1 s using Euler's method and a time step size of 0.1 s

ii) Discuss with evidence the effect of the time step size on the accuracy of the prediction using Euler's method.

iii) Between 0 and 1s, find the time corresponding to the occurrence of the maximum displacement of the hub using the bisection method.

Marking and participation

- For all tasks, the weighting is 75% for getting correct solutions and 25% for providing sufficient comments.
- Formative feedback can be given through an in-person or online meeting 1 week before the submission deadline.
- You are expected to meet your group members during lab sessions. Prof Stallebrass and I will meet each group randomly during the lab sessions to monitor your progress and participation.